International Journal of Electrical, Computing Engineering and Communication (IJECC)

Vol. 1, Issue. 1, January – 2015 *ISSN (Online): XXXX-XXXX*

Analysis of Group Velocity Dispersion (GVD) with and without initial Gaussian Chirp in different types of fiber

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Abstract—In this work, the effect and mechanism of Group Velocity Dispersion (GVD) in conventional single mode fiber (SMF), Enhanced- Large effective Area Fiber (E-LEAF) and true wave fiber is studied. The mechanism of GVD is noted with chirped and unchirped Gaussian input pulse. First, the effect of pulse broadening is noted with an unchirped pulse for various Dispersion lengths (L_D) in the 20 Gbps system. Secondly, the effect of chirped pulse with an initial chirp (C) of 3 rad/sec is studied for various lengths. It is noted that the minimum pulse broadening for chirped pulse occur at the distance of 13.26 km while the dispersion length of E-LEAF without SPM is 44.21 km and also the similar analysis is taken for other fibers. Thus, the power in this case at the distance of 13.26 km, where the initial narrowing occurs is found to be 3.32mW.

I.INTRODUCTION

The modern optical communication focuses on building up ultra-high capacity system. The increase in capacity was made by increasing the bitrate to single channels, but later the concept of transmitting various laser colors (wavelengths) as virtual fibers in a single fiber introduced the concept of Wavelength Division Multiplexing (WDM). The system capacity was increased by increasing number of channels in the system (DWDM)[1]. But the demand of bandwidth from the population side upgraded the optical system to contribute high bitrate to individual channels in multichannel systems. So the contribution of very high bitrate (several Gbps) needs very closed spacing of pulses which is highly pronounced to intra channel impairments. The effect of Inter-symbol Interference (ISI) is deadly high in such system even with small dispersion. The effect of dispersion cause a pulse broadening while pulse travel along a optical fiber due to various phenomenon. Normally, Conventional Single Mode Fiber (C-SMF) has large dispersion co-efficient around 17ps/nm/Km in 1550 nm transmission window. But the E-LEAF has small dispersion value around 4ps/nm/Km which helps in long distance transmission than the C-SMF does. So, E-LEAF supports high bitrate and long haul transmission for modern optical transmission systems [2][3].

The effect of GVD on Gaussian pulse as an input is noted with and without chirp. Since,, the GVD depends on the instantaneous frequency changes (chirp). So, the system is characterized for its performance of chirping in the pulse.

II. GROUP VELOCITY DISPERSION

The optical pulse travelling in fiber is governed by various dispersion wave equations as given by the Taylor series expansion

$$H(\omega)=\exp\{Jz[\beta_0+\beta_1(\Delta\omega)+\frac{1}{2}\beta_2(\Delta\omega)^2+\frac{1}{6}\beta_3(\Delta\omega)^2+\ldots]\} \tag{1}$$

Where $\beta_m=(d^m\beta/d\omega^n)_{\omega=\omega0}$,and $\omega_0$is the operating frequency.

The another equation is governed by Nonlinear Schrodinger equation as,

$$\frac{\partial A(z,t)}{\partial z}=\frac{-\alpha}{2}+i\frac{\beta 2}{2}\frac{d2A}{dt2}+\frac{\beta 3}{6}\frac{\partial 3A(z,t)}{\partial t3}-i\gamma|A(z,t)|^2A(z,t) \tag{2}$$

first order GVD which is characterized by following equation

$$D=\frac{d}{d\lambda}\left(\frac{1}{Vg}\right)=-(2\pi c/\lambda^2)\,\beta_2 \tag{3}$$

Cis the velocity of light in vacuum, λis the wavelength,$\beta_{2.}$ is the second order expansionThe corresponding transfer equation is given by

The third order dispersion is given by means of dispersion slope,

$$S=\frac{dD}{d\lambda}=(2\,\pi c/\lambda^2)\,\beta_3+(4\,\pi c/\lambda^3)\,\beta_2 \tag{4}$$

Where s-dispersion slope which is characterized for second order dispersion and its non-linearity. Gaussian pulse is considered for the experimentation with initial power and pulse width of P_0 and T_0 respectively. The Gaussian profile with the amplitude A(z) is represented as follows,

$$\mathbf{A\ (z=0,\ t)} = \sqrt{P0}\,\mathbf{exp\ (-t^2/2T_0^2)} \quad \textbf{(5)}$$

The time domain broadening [T(z)] and [P(z)] of Gaussian shaped electric field envelope in the eqn(2) at the distance z with the dispersion length as Ld can be given as

$$\mathbf{T(z)=[1+(z/L_D)^2]^{1/2}\ T} \quad \textbf{(6)}$$

$$\mathbf{P(z)=P_0/[1+(z/L_D)^2]^{1/2}} \quad \textbf{(7)}$$

Such that from eqn (3) and (4),it is easily understood that at the distance of dispersion length($z=L_D$),the broadening increase and power decrease by factor of $\sqrt{2}$ since we are dealing with the focused experimentation of GVD ,the eqn (1) can be given as follow by neglecting the attenuation , kerr non linearity and second order GVD as

$$\mathbf{i\frac{\partial A(z,t)}{\partial z}=\frac{\beta 2}{2}\partial^2 A/\partial t^2} \quad \textbf{(8)}$$

where $\beta_2=\partial^2\beta/\partial\omega^2$ (GVD parameter) is the relation of second order derivative of fiber mode propagation constant to the frequency .the GVD is characterized by a main parameter called dispersion length is given by

$$\mathbf{L_D=T_0^2/|\beta_2|} \quad \textbf{(9)}$$

Profile of envelope of the electric field is given as

$$\mathbf{A\ (0,\ T)=exp[-(1+ic)T^2/2T_0^2]} \quad \textbf{(10)}$$

The spectral half width is noted as

$$\mathbf{\Delta\omega=(2\pi T_0^2/1+ic)^{1/2}exp[\omega^2T^2{}_0/2(1+ic)]} \quad \textbf{(11)}$$

The pulse broadening propagating through a distance z is given by

$$\mathbf{T_1/T_2=[(1+c\beta_2 z/T_0)^2+(\beta_2 z/T_0)^2]^{1/2}} \quad \textbf{(12)}$$

The chirp parameter (C) changed for various value and the minimum distance of transmission without broadening or initial pulse calculated from the following equation as,

$$\mathbf{Z=\frac{c}{1+c2}L_D} \quad \textbf{(13)}$$

While the pulse width along the distance and power in this case is given in (11) and (12) respectively

$$\mathbf{T\ (Z_{min})=T_0/\ (1+c^2)^{1/2}} \quad \textbf{(14)}$$

$$\mathbf{P\ (Z_{min})=P_0\ (1+c^2)^{1/2}} \quad \textbf{(15)}$$

III. SIMULATION SETUP

The parameters to be considered for designing the chirping based system is tabulated for E -LEAF and SMF as follows,

S.no	Parameters	Values	Values	Units
1.	Reference wavelength(λ)	1550	1550	nm
2.	Dispersion Coefficient(D)	4	16	ps/nm.Km
3.	Dispersion Slope(S)	0.085	0.06	$ps/nm^2/Km$
4.	Attenuation(α)	0.2	0.2	dB/Km
5.	Effective Area(Aeff)	72	80	μm^2
6.	Non-linear coefficient(γ)	$1.52x10^{-20}$	$1.31x10^{-20}$	$W^{-}Km^{-1}$

And also the block diagram module is listed as follows,

1. User Defined Bit Sequence
2. Optical Gaussian pulse Generator
3. Optical fiber
4. Receiver

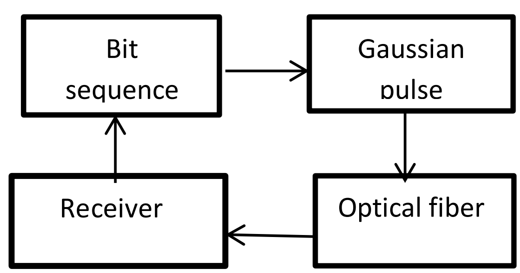


Fig.1.Blockdiagram of chirping compensation

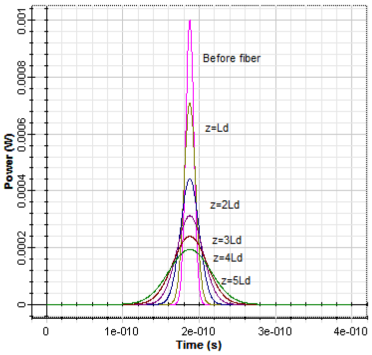
The system is operated with the bitrate of 20Gbps. The bit width is the inverse of bitrate, so T becomes 50ps (1/bitrate). The default value is 0.5 bit. So, T becomes 25ps. The initial pulse width and TFWHM is related by To~TFWHM/1.665. Now, the initial pulse width is calculated as 15.02ps. The Dispersion length (LD) is calculated from eqn.6 by considering β2=-5.1 ps^2/km as 44.21km.

When considering chirped Gaussian pulse the broadening is given by the eqn.9. In case of the chirped pulse the initial narrowing is calculated from the eqn.10 which gives the minimum distance. By substituting the Chirp parameter (C) as 3rad/sec. in the eq.10, the value of z becomes 13.26km. At this case the peak power is found to be 3.32mW which can be seen from following figures.

Vol. 1, Issue. 1, January – 2015 *ISSN (Online): XXXX-XXXX*

IV. RESULTS AND DISCUSSIONS

The unchirped pulse is applied through the optical fiber with designed calculation andthe unchirped pulse is simulated at various dispersion lengths (LD) and the broadening of the pulse with respect to the distance in noted in fig.2(c). The concept of broadening can be clearly understood from fig.2(a) and fig.2(b), where the fig.2(a) shows the chirp less input pulse with 1mW input power in 20Gbps system.



But, the pulse received after the dispersion length of 44.21 km shows the presence of chirping across the pulse that can be pictured in fig.2(b). The chirping constantly decreases from the leading edge to the trailing edge depicts the presence of higher frequency in the leading edge and lower frequency in the trailing edge.

The following graph gives the clear explanation about the flow of processing of light pulse before and after fiber.

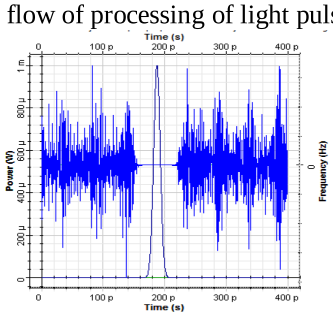


Fig.2.a.unchirped pulse before the fiber

The chirped pulse with broadening after traveling out from the fiber,

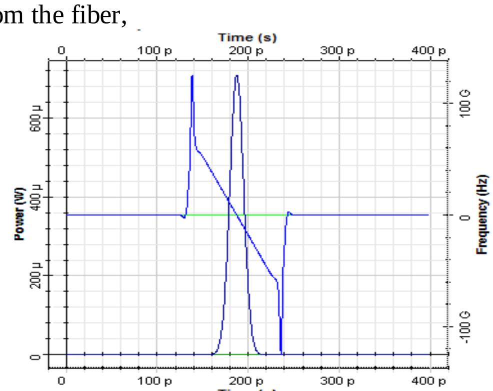


Fig.2.b. chirping pulse after fiber.

Fig..2.c comparative study between dispersion length

Which shows the constantly decreases from theleading edge to the trailing edge depicts the presence of higher frequency in the leading edge and lower frequency in the trailing edge.

In similar way, the pulse broening effect is measured at various dispersion length(LD) after fiber fig.4.is shown below,

Fig.4.comparative study of pulse broadening

The above graph is plotted between time and pulse power for various dispersion lengths and shows that it will be broadened for the increasing order of dispersion length.

By introducing the chirping on pulse, the pulse broadened effect is analyzed and minimized with the sake of minimum dispersion length of fig.5. as shown below,

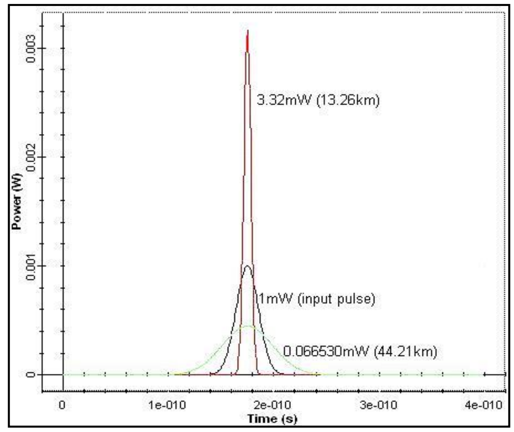


Fig.2d. chirped pulse input and output of the fiber

The clear picture on chirped pulse where the power increased to 3.32 mW (refer the equation 3.14) at the minimum distance z=13.26 km where the broadening is minimum. Thus, the chirped pulse broadens gradually and reaches power with the power of ~0.07mW at the distance of dispersion length (L_D=44.26km).

The main impact of chirping parameters(c) made a effect trailing edge to leading edge to trailing edge which shown from fig.7.

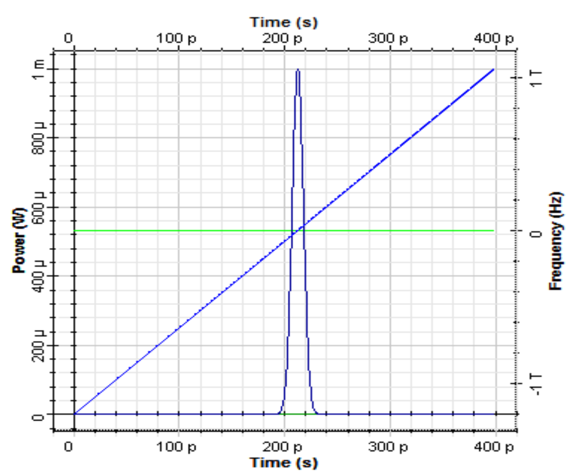


Fig.5.chirped Gaussian pulse at the input

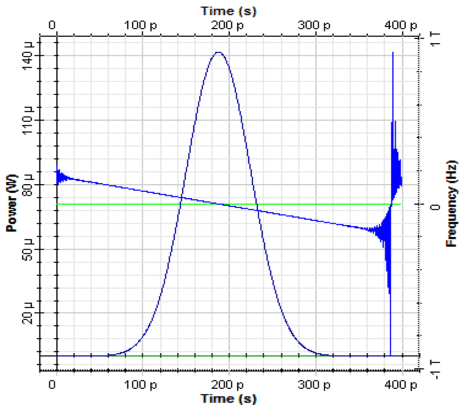


Fig.8.chirped Gaussian pulse at the output

the case of unchirped pulse the chirping is seem to be decreasing from the leading edge to trailing edge (blue frequencies in the leading edge and red frequencies in the trailing edge)which is the characteristic feature of GVD in the anomalous regime at the dispersion length.

In similar way the comparison study between the chirped pulse for various dispersion length is measured at various fiber , they can be shown in following figure,

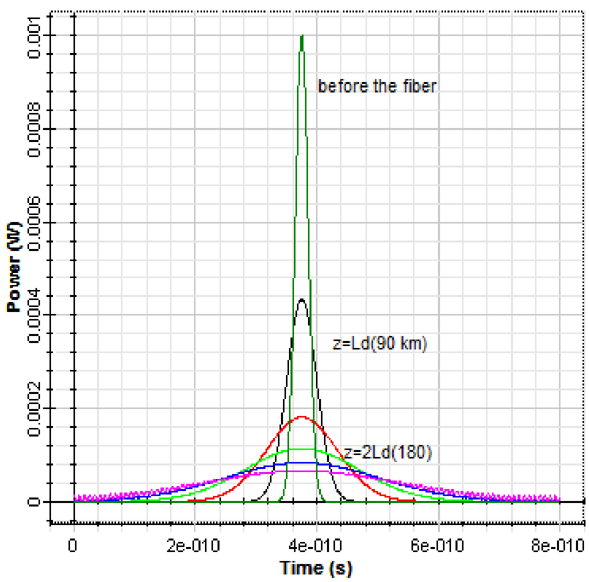


Fig.9.comparison study for true wave fiber

The comparison table is given below when different types of fiber for chirped managed system,

Fiber Types	**Initial Pulse Width** (T_0)	**Dispersion Length Ld (km)**	**Minimum Dispersion Length Zmin(km)**	**Peak Power (mw)**
SMF	50 Ps	15 Ps	11.25	3.375
E-LEAF	50 Ps	15 Ps	44.21	13.26
TRUE WAVE FIBER	50 Ps	15 Ps	88.26	26.478

Distance of 3D plot is considered with optical pulse evolving device for before the chirping and after the chirping,

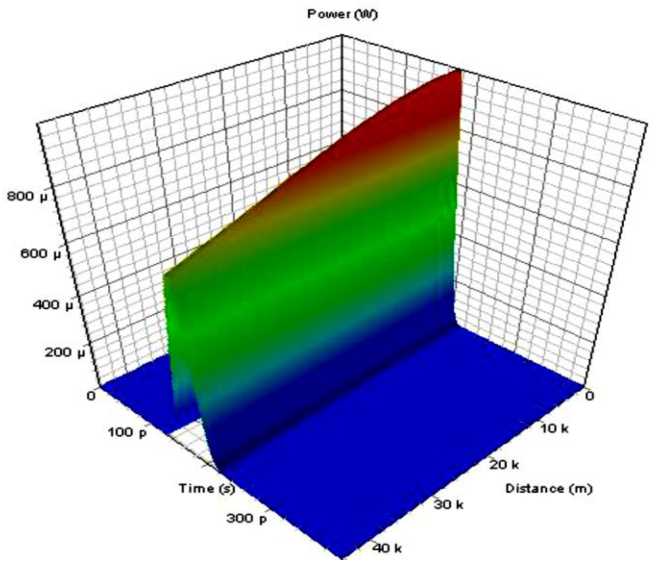


Fig.10. unchirped input pulse

The chirped pulse as shown by 3D axis cut model,

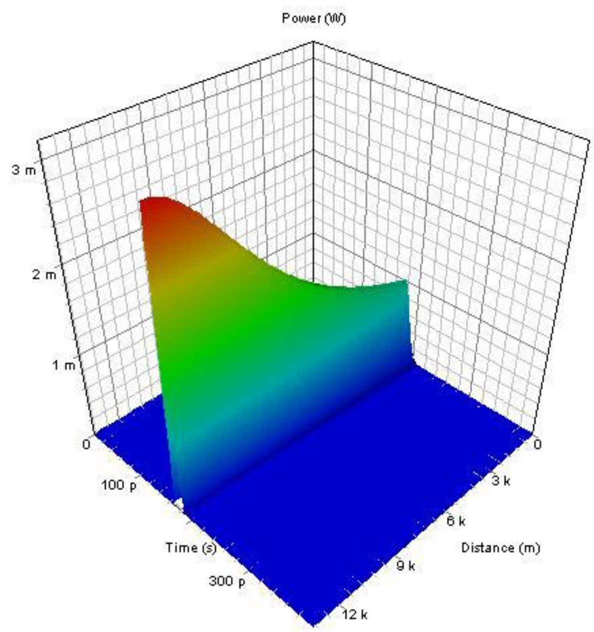


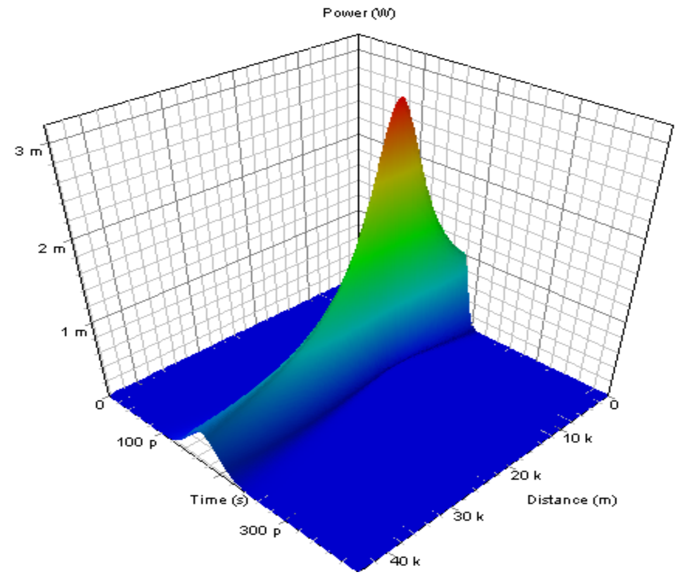
Fig.11.chirped pulse at the distance of 44.21 km. The resultant pulse at the calculated

Fig.12.chirped pulse at the distance 13.21km

Where the faster blue components in the trailing edge overtakes the slower red components in the leading edge till the minimum distance limit of 13.26Km. Hence narrowed pulse occur at 13.26Km.

V.CONCLUSSION

The effect of E-LEAF fiber with respect to the Conventional Single Mode Fiber is demonstrated by numerical simulations. The effect of GVD has less impact on E-LEAF than C-SMF which can be proved by the Dispersion length for various bitrates. Thus, E-LEAF



forms an effective transmission with its attracting low dispersion co-efficient and large effective area. It can be also noted that the large effective area can decrease the non-linearity in optical telecommunication systems where other practical telecom fibers with less dispersion constant has small effective area. The effect of GVD with and without initial Gaussian chirping helps to understand that E-LEAF and TW fiber transmission without Dispersion Compensation Fiber (DCF) for long distance than C-SMF as DCF is more pronounced to non-linearity due to smaller effective area of 16-21 µm2.

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